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Natural Manuring and Soil Conditioning by Dung Beetles

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Abstract : To assess the role of dung beetles in conditioning and revitalizing the soil, field and laboratory studies were conducted on three species: *Onitis philemon* F., *O. virens* Lansb. and *Onthophagus catta* (F.). In addition to dung burial and soil excavation, the depth and diameter of their burrows, the nitrogen deposited and the work performed per unit area were also recorded. Dung incorporated per burrow was maximum by *O.virens* (43.8±6.1 g), followed by *O. philemon* (21.2±0.9 g) and *O.catta* (1.6±0.2 g). However, the total work done in an area depended on their population density. Accordingly, the amount of dung deposited per hectare was largest by *O. philemon* (10.6 kg), followed by *O. virens* (6.6 kg) and *O.catta* (1.4kg).

Résume : Pour mettre en évidence le rôle des bousiers dans le conditionnement et la régénération du sol, des études de terrain et de laboratoire ont été menées sur trois espèces: *Onitis philemon* F., *Onitis virens* Lansb. et *Onthophagus catta* (F.). L'enfouissement du fumier et le creusement du sol furent mesurés ainsi que la profondeur et le diamètre des galeries, l'azote déposé et le travail fourni par unite de surface. Le fumier incorporé par galerie est maximum pour *O. virens* (43,8 ± 6.1g), suivi de *O. philemon* (21,2 ± 0,9 g) et *O. catta* (1,6 ± 0,2 g). Toutefois, le travail total fourni dans une zone dépend de la densité de population. Le taux de fumier enfoui par hectare est maximum pour *O. philemon* (10,6 kg) suivi de *O. virens* (6,6 kg) et *O. catta* (1,4 kg).

Resumen : Para determinar el papel de los escarabajos estercoleros en el acondicionamiento y revitalización del suelo, se realizaron estudios de campo y laboratorioen tres especies: *Onitis philemon* F., *O. virens* Lansb. y *Onthopagus catta* (F.). Además del estiércol enterrado y la excavación del suelo, también se registraron la profundidad y diámetro de sus túneles, el nitrógeno depositado y el trabajo realizado por unidad de área. El estiércol incorporado por túnel fue mayor para *O. virens* (43.8 ± 6.1 g), seguido por *O. philemon* (21.2 ± 0.9 g) y *O. catta* (1.6 ± 0.2 g). Sin embargo, el trabajo total hecho en un área dependió de la densidad poblacional. Paralelamente, la cantidad de estiércol depositada por hectárea fue más grande para *O. philemon* (10.6 kg), seguida por *O. virens* (6.6 kg) y *O. catta* (1.4 kg).

Resumo: Para avaliar o papel dos escaravelhos do esterco no condicionamento e revitalização do solo, foram efectuados estudos laboratoriais envolvendo três espécies: *Onitis philemon* F., *O. virens* Lansb. e *Onthophagus catta* (F.). Adicionando-se à avaliação do enterramento de estrume e à escavação do solo, a profundidade e diâmetro das galerias, a deposição de azoto e o trabalho efectuado por unidade de área foram igualmente registados. O estrume incorporado por galeria foi mais elevado para o *O. virens* (43,8±6,1 g), seguindo-se o *O. philemon* (21,2±0,9 g) e *O. catta* (1,6±0,2 g). Verificou-se, contudo, que o trabalho total efectuado numa área dependeu da densidade populacional. Assim o montante de estrume depositado por hectare foi maior para o *O. philemon* (10,6 kg), seguindo-se o do *O. virens* (6,6 kg) e *O. catta* (1,4 kg).

Key Words : Dung beetles, Scarabaeidae, *Onthophagus catta, Onitis philemon, Onitis virens,* burrows, dung burial, soil excavation, nutrient cycling, nitrogen.

INTRODUCTION

Though there are several insect groups which utilize waste organic matter, dung beetles of the family Scarabaeidae are most significant in consuming and dispersing the excrement of large mammals. These beetles bury dung in soil as food for themselves and for their larvae. The dung buried is not completely consumed by them and a major part of it remains in burrows along with the beetles' own excreta (Lindquist 1933). The burying and burrowing habits of these beetles help in building soil in several ways. They aerate it by making burrows and turning it out depositing it on the soil surface, and fertilize it by adding nutrients by incorporating faecal matter. Ecologists have regarded such activities as beneficial in that the nutrients are recycled more efficiently and quickly. Some other benefits of these activities include the disintegration and decomposition of dung pats in pastures which prevent pasture wastage and make dung unsuitable for multiplication of pest flies and enteric parasites (Mohr 1943; Bornemissza 1960, 1979; Fincher 1973, 1975; Ferrar 1973, 1975; Hughes *et al.* 1978; Holter 1979; English 1979 and Doube & Moola 1988). In India, the scarabaeid fauna takes large amounts of dung daily into the soil. Hingston (1923) estimated that 40-50 thousand tons of human excrement alone was carried daily by these beetles during the active season.

Although the edaphic relationships of these beetles are known to naturalists and ecologists for a long time, only few qualitative and quantitative studies are available; e.g., those by Lindquist (1933, 1935), Miller (1954), Teichert (1959), Halffter & Matthews (1966), Myrcha (1973), Hughes (1975), Ridsdill-Smith & Kirk (1982), Ridsdill-Smith *et al.* (1982), Cambefort (1984), Brussaard & Visser (1987) and Doube *et al.* (1988), on the role of dung dispersal by these beetles in some parts of the world. On the Indian subcontinent, where the fauna is rich and endemic, such information, except for one small study (Mittal & Yadava 1979), is lacking.

The potential nutrient value of dung deposited in soil has been verified by some workers. In a comparison with various artificial fertilizers, Levy (1955) stressed the value of dung. Gillard (1967) observed that 80% of faecal volatilizable N could be absorbed by soil colloids if the beetle activity was rapid and dung was incorporated before it was dry. The beneficial effect of dung beetle activity on plant life and pasture ecosystem has been studied by Bornemissza & Williams (1970), McKinney & Morley (1975), Rougon & Rougon (1981) and Fincher *et al.* (1981). These studies performed in several vegetation types indicated that not only was plant nutrient uptake and yield increased but forage fouling was eliminated when dung was carried quickly into soil by these beetles.

In view of the importance of dung beetles in soil enrichment, the present work carried out in a dry tropical region investigated dung beetle activity both in field and in laboratory conditions, by determining the amount of dung buried and soil excavated by each species, and by assessing their role in nitrogen conservation.

MATERIALS AND METHODS

Most of the material for the present investigations was collected from Kurukshetra (latitude 29°58' N, longitude 76°51' E) and its vicinity. Climatically, it is an arid zone in the subtropical region with an average rainfall of 75 cm (mainly monsoonic). The maximum and minimum average temperatures range between 32°±1°C and 18°±1°C highest being 43°±2°C and lowest 5°±2°C, respectively. The soil is old alluvium type and its structure is varying from sandy-loam to clay-loam.

The three species, *Onitis philemon* F., *O. virens* Lansb., and *Onthophagus catta* (F.) (Scarabaeinae: Scarabaeidae), were selected because of their size, abundance and availability in the area. Field

studies were made mostly in August and September months (for 26 days) in all types of habitats including patches of woodlands, grazing lands, small tree stands, agricultural lands, forest plantations, waste lands around villages and road sides, and some sandy areas near water bodies and riverines, etc. The woodlands were open canopy forest systems dominated by *Dalbergia sissoo* and *Acacia nilotica*. Forest plantations of *Eucalyptus hybrid* and *Populus deltoides* have been raised on large areas mostly in strips. Agriculture was predominant land use having different crop rotations, the common being annual wheat and rice rotation. Waste lands supported scanty vegetation of grasses and forbs. The excavated soil in the vicinity of infested dung droppings was collected in plastic bags and the burrows opened to find the beetles and the buried dung. The diameter and vertical depth of burrows were recorded.

Laboratory studies were restricted to *Onitis philemon* and *Onthophagus catta*, as *Onitis virens* could not be found in sufficient numbers. A set of four specimens of each species (2 males, 2 females) was put in each of four earthen jars (25 cm diameter) containing 30 cm soil. The field soil used was first oven dried and sieved, producing a lower bulk density (1.08) than in the field (1.48). For larger species (*O. philemon*) 300 g and for smaller (*O.catta*), 100 g of fresh cattle dung was kept in the jars. For five consecutive days, the dung consumption was calculated after every 24 h both indirectly by weighing the remaining dung on the surface and directly by weighing the dung which had been buried. The depth of buried dung was recorded but the diameter of burrows could not be measured because of soft crumbling soil.

To assess the amount of dung buried in the field, the number of fresh burrows made by each species in two 20 m x 20 m plots in four different areas were counted. The N concentration in dung was estimated by the Macro-Kjeldahl method in 20 samples.

RESULTS

The burrows usually increased in diameter with increasing depth and were mostly oblique. The diameter and depth of burrows generally depended on the number and sex of the beetles occupying them. The large sized tunnels invariably belonged to a pair, the medium ones were occupied by females and the smallest usually by males. Likewise, the quantities of soil excavated and dung buried were affected by the sex and number of beetles.

For *Onitis philemon,* the mean of eighty burrows was 1.2±0.1 cm (range 0.6-1.7 cm) diameter and 22.7±2.6 cm (range 8.3-38.5 cm) depth (Table 1). The amount of soil excavated varied from a minimum of 10.3 g to maximum 190.6 g (mean 53.4±4.9 g) and dung buried from 4.1-90. 3 g (mean 21.2±0.9 g) per burrow. Of the 80 observations, male and female cooperation was noticed in only 18 cases and maximum burrows were occupied by females (38 cases).

Under laboratory conditions, the depth of burrows varied from 2.1-24.7 cm (mean 13.4±0.8 cm) and the dung stored ranged from 1.0-22.7 g (mean 9.3±0.7 g) (Table 2). Sex cooperation was observed in only 7 out of 80 instances.

O. virens was larger in size but less abundant. The mean diameter and depth were 1.5±0.0 cm (range 1.3-1.8 cm) and 30.9±1.1 cm (range 24.4-38.7 cm), respectively. The mean of the soil excavated and dung buried were 101±14.7 g (range 49.8-195.4 g) and 43.8±6.1 g (range 20.1-94.2 g), respectively (Table 1). In 14 observations male-female cooperation was found only in a single case, maximum number of 8 burrows was occupied by females.

TABLE 1. Summarized field data on the burrows of three species of dung beetles.

	No. of Observations	Mean	SE	Conf. Interval (P<0.05) Mean±
Diameter (cm)				
Onitis philemon	80	1.2	0.1	0.3
Male	23	1.0	0.1	0.1
Female	38	1.2	0.2	0.4
Male & Female	19	1.3	0.1	0.1
O. virens	14	1.5	0.0	0.1
Male	4	1.5	0.1	0.3
Female	9	1.5	0.0	0.1
Male & Female	1	1.6	0.0	0.0
Onthophagus catta	77	0.6	0.0	0.0
Male	27	0.6	0.0	0.1
Female	30	0.6	0.2	0.4
Male & Female	20	0.7	0.0	0.1
Depth (cm)				
Onitis philemon	80	22.7	2.6	5.0
Male	23	17.8	1.2	2.5
Female	38	22.6	3.7	7.3
Male & Female	19	28.8	0.9	1.9
O. virens	14	30.9	1.1	2.5
Male	4	27.1	1.4	4.3
Female	9	31.9	1.2	2.8
Male & Female	1	37.6	0.0	0.0
Onthophagus catta	77	9.3	0.5	1.0
Male	27	7.0	0.6	1.3
Female	30	9.5	1.4	2.9
Male & Female	20	12.1	1.1	2.2
Soil Excavated (g)				
Onitis philemon	66	53.4	4.9	9.6
Male	15	26.8	2.9	6.1
Female	32	45.7	3.7	7.2
Male & Female	19	87.5	9.6	20.2
O.virens	13	101.0	14.7	31.9
Male	3	73.1	4.3	18.3
Female	9	99.9	17.5	40.4
Male & Female	1	195.4	0.0	0.0

Table 1 (contd.)

Table 1 (contd.)

Onthophagus catta	59	17.1	1.1	2.1
Male	15	13.6	2.4	5.1
Female	26	15.3	0.6	1.1
Male & Female	18	22.7	2.2	4.7
Dung buried (g)				
Onitis philemon	74	21.2	0.9	1.7
Male	17	11.4	1.1	2.4
Female	38	17.9	2.9	5.7
Male & Female	19	36.7	5.2	10.8
O. virens	14	43.8	6.1	13.3
Male	4	27.9	4.2	13.4
Female	9	45.3	6.5	15.1
Male & Female	1	94.2	0.0	0.0
Onthophagus catta	74	1.6	0.2	0.3
Male	24	0.6	0.1	0.2
Female	30	1.4	0.1	0.2
Male & Female	20	3.2	0.3	0.6

TABLE 2. Laboratory studies on dung deposition and depth of burrows of *Onitis philemon* & *Onthophagus catta.*

	No. of Observations	Mean	SE	Conf. interval (P<0.05) Mean ±
Dung buried (g)				
Onitis philemon	73	9.3	0.7	1.3
Onthophagus catta	80	0.9	0.1	0.1
Burrows depth (cm)				
Onitis philemon	73	13.4	0.8	1.6
Onthophagus catta	80	6.6	0.5	0.9

Onthophagus catta was very common. The burrows were of 0.6 cm (range 0.3-1.0 cm) diameter and 9.3±0.5 cm (range 2.5-21.7 cm) depth. The soil excavated was 17.1±1.1 g (range 6.9-21.3 g) and dung buried 1.6±0.2 g (range 0.5-2.5 g) (Table 1). Male-female cooperation was noticed in 20 out of 77 cases studied, male occupied 27 burrows and female 30.

In the laboratory, the mean amount of dung buried was only 0.9±0.1 g (range 0.2-2.2 g) and depth to which the dung buried was 6.6±0.5 cm (range 1.2-17.5 cm) (Table 2).

Nitrogen concentrations of the dung ranged from 1.65-1.9% (average 1.8%). However, no account was taken of the volatile nitrogen in the fresh dung.

To assess the role of dung beetles per unit area, fresh burrows of the three species were counted over one hectare. *O. catta* was found to be the most common (850 burrows/ha), followed by *O. philemon* (500) and *O. virens* (150). As the dung buried and soil excavated per *O. catta* burrows was 1.6 g and 17.1 g, the mean rate per hectare was 1.4 kg and 14.5 kg, respectively. Likewise, the amounts of dung buried and soil excavated by *O. philemon* and *O. virens* were 10.6 kg and 26.7 kg, and 6.6 kg and 15.2 kg, respectively. The three species together would excavate approximately 56.4 kg/ha/day of soil and bury 18.6 kg/ha/day of dung, thus incorporating the equivalent of 334 g N in the soil.

The activity of the three species, under observations for over two months of the rainy season, exhibited some common trends with response to weather factors. Their activity declined with decrease in temperature and rainfall during the period (Fig. 1). In general, the peaks in their activity occurred within a few days of heavy rains, and low activity periods after a spell of comparatively dry days. The work performed by the three species individually on day to day basis has been compared in Fig. 2.

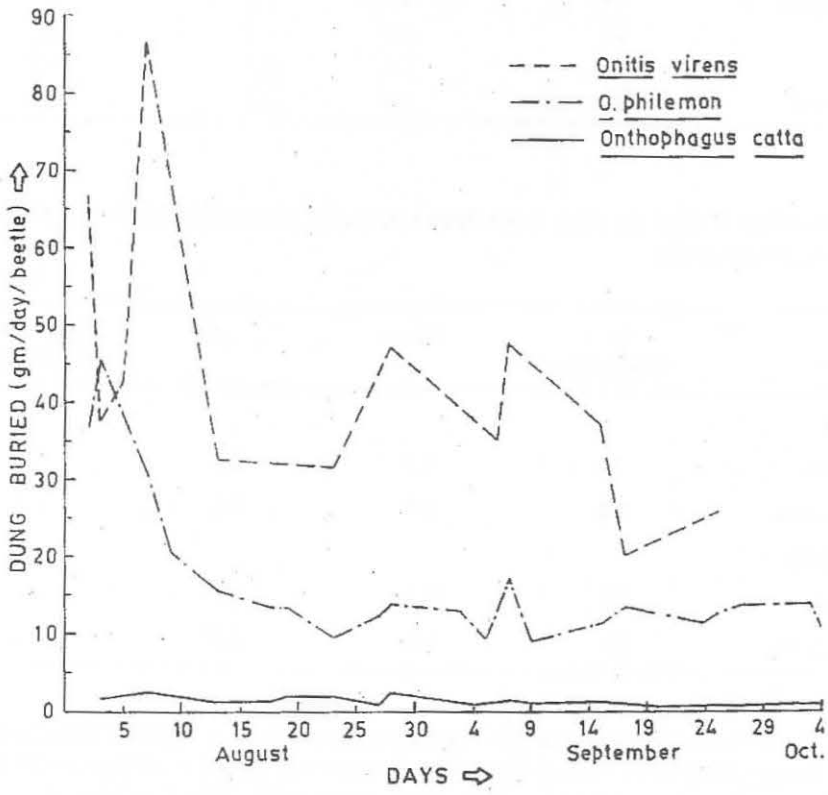

Fig. 1. Fluctuations in the working (dung/day) of three species with respect to seasonal factors.

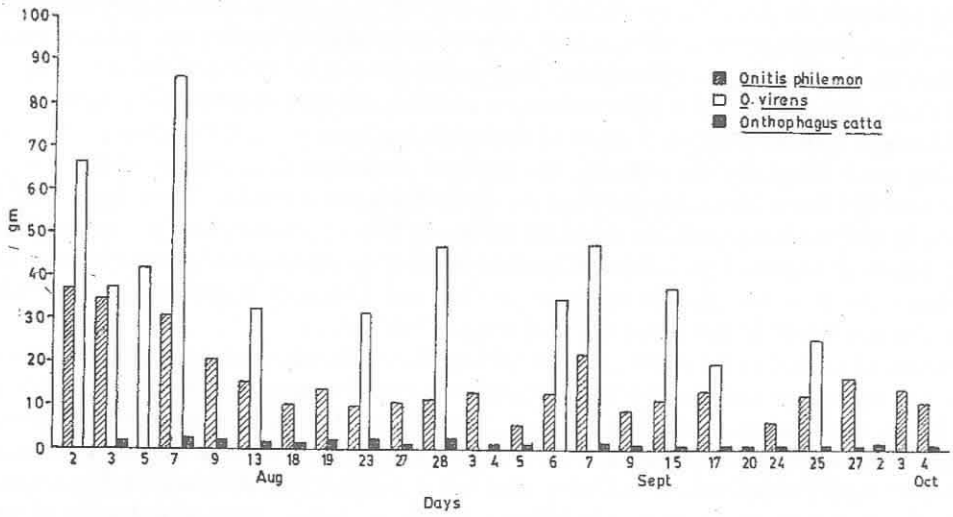

Fig. 2. A comparison of the working (dung/day) of three species in the field.

DISCUSSION

The mean individual work performed by each species was relative to its size, as the amount of dung buried and soil excavated was greatest in the largest species, *O. virens,* and the least in the smallest, *O. catta.* But their wide working ranges overlapped considerably. For example, large segments of the total range of dung burial (20.1-94.2 g and 4.1-90.3 g) and soil excavation (49.8-195.4 g and 10.3-190.3 g) of *O. virens* and *O. philemon,* respectively, were overlapping. Though the mean values of dung buried and soil excavated by *O. virens* were almost double the values for *O. philemon,* the similar amount of work performed on many occasions did indicate that it was not size alone which determined the amount of work performed by a species, but other factors, such as their vigour (Hughes 1975), atmospheric and soil conditions and competition, etc., as well did have their limiting role. For the total work performed in an area, however, the population density of the species, seemed to be more responsible. The maximum amount of individual work of *O. virens* fell behind the other two species in the field only because of its low abundance.

The three paracoprid species were not in competition with each other because of their size differences. Under the highly infested dung pats they were not competing even for the burial space, as they were in the habit of burying dung at different levels. Whereas *O. catta* buried mostly in the top soil layer, *O. philemon* and *O. virens* carried the dung deeper at two different levels. The three species, though selected randomly for the present investigation because of their availability in the area, formed together a very potent guild of beetles, in avoiding mutual competition and enriching

various soil levels, for employing in the areas of scarcity for natural manuring.

The activities of two species, i.e., *O. philemon* and *O. catta*, when studied in the laboratory, differed from their activities in the field. *O. philemon* buried almost half the amount of dung, to half of the depth of that in the field. In case of *O.catta*, the differences, however, were only by one-third approximately. As the simulated conditions in the laboratory could never be the same as in the field, the differences might be obvious. Although the dung provided was more or less of the same quality as in the field, the soil condition was different because of its low density (lowered from 1.48 to 1.08). The beetles might feel discouraged because of the crumbling burrows in making many trips for accumulating more dung. On the contrary, the changed conditions in laboratory could play a favourable role. The free access to food without any competition, and loose soil easy to dig in, might enable them to perform more work. As discussed earlier, there were other factors, too, responsible for the differences in quantities of work performed and for the large variation in one's work, the same factors might as well account for the difference in field and laboratory conditions, as the value obtained under lab conditions fell within the total range of field values.

The amount of work done by various species all over the world, when compared, gave a varied picture. It was natural for different species to differ in their performance, but the different values obtained for the same species in different parts of the world, could be either because of different climatic conditions or for the data obtained under different facilities to beetles. Present values for *Onitis*, when compared with Lindquist's (1933), were less than that of *Pinotus*, but more than *Copris* and *Phanaeus*. However, in comparison to Miller's (1954), the values were almost same as for *Dichotomius* and more than *Phanaeus*. For *Onthophagus*, burrow depths were mostly the same. Geotrupids seemed to be one of the most efficient group as they could bury as much as 500-725 g dung per nest (Teichert 1959). The mass of dung buried per pair of large coprine beetles was 100-300 g and of onitine beetles 400-1000 g (Doube *et al.* 1988). Dung buried by *Copris lunaris* varied from 300 g (central Europe, Teichert 1959) to only 75 g (Poland, Myrcha 1973), and in case of *Copris fricator*, the average value was 7.3 g only.

Under laboratory conditions, the values for *O. philemon* were almost the same as of *Catharsius pithecius* (Mittal & Yadava 1979) more or less of the same size. For *Onthophagus binodis* in Australia, Ridsdill-Smith *et al.* (1982) estimated the amount of dung buried by about 35 beetles per dung pat as 800-900 ml.

The amount of soil excavated (56.4 kg/ha/day), dung buried (18.6 kg/ha/day) and faecal N incorporated (334 g/ha/day) had been estimated here for three species of dung beetles only. As India has very rich dung beetle fauna, the amount of work performed would be much greater if it was estimated for all the active species working in the field. Further, if their performance was considered for whole of the active period and as the total process was repeated year after year, the total amount of work would be so tremendous as to add significantly to the soil friability, aeration, moisture retaining capacity and nutrient cycling.

The major contribution of dung deposition to the soil by these beetles, however, was considered in its N contents. Gillard (1967) provided the first actual measurement of amount of faecal nitrogen returned by the beetles to the soil. Soil analysis of grassland patches covered with faeces after six weeks of beetle activity showed that the amount of additional nitrogen in the soil due to cattle faeces was about 360-380 lb per acre, which represented a loss of only 5-15% of nitrogen by volatilization compared to 80% of N losses from the faeces which were not buried by beetles. Bornemissza & Williams (1970) recorded that the dung beetle activity was of great benefit to plant life and the plant uptake of N was increased from 8.3% without beetles to 21.9% with beetles. McKinney & Morley

(1975) while studying the agronomic role of dung beetles also concluded that the burial of dung reduced losses of N from faeces and permitted the use of N by plants for a year or two. In the field test conducted by Fincher *et al.* (1981) on Coastal bermudagrass, the dung beetles buried 175 kg N/ha and their results indicated that there was no significant difference in the yield of this plot with buried faeces from that receiving 224 kg/ha of N fertilizer. It was, therefore, evident that while a substantial part of faecal N would go waste in the absence of dung beetle activity, in their presence it was incorporated in the soil and significantly utilized for high plant yield.

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